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An Evaluation of the Impacts of ITS/CVO Technologies on Safety and the Associated Benefits Throughout the Supply Chain

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An Evaluation of the Impacts of ITS/CVO Technologies on Safety and the Associated Benefits Throughout the Supply Chain

Phase I: A Review of Literature and Case Study Analysis

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This Phase I Report contains a brief description of Intelligent TRansportation Systems (ITS) and ITS technologies for Commercial Vehicle Operations (ITS/CVO). Second, it discusses previous literature regarding benefits of ITS/CVO for motor carriers, as well as managing the change due to technology. In addition, the possible use of transportation-inventory models as a method to examine benefits is explored. Finally, this methodology is illustrated with a case study analysis which revelas potential savings to both the company and their customers. Phase II of this project will involve data collection for a stratified random sample of carriers nationwide, and a subsequent detailed analysis for a wide variety of technologies and types of companies.

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EXECUTIVE SUMMARY

The trucking industry is extremely competitive. Companies must vie for business through both lower rates, and more importantly, superior service. One potential strategy for a motor carrier company to better their service offering is through investment in technology. However, commercial vehicle companies are in a precarious position. They realize that they need to invest in technology to remain competitive, but are unsure which innovations will give them the desired results.

The right technology, implemented correctly, can positively affect on-time performance, equipment and driver utilization, as well as reduce en-route delays, accidents, empty miles, and administrative costs. The main problem is to determine which technologies will contribute to these positive affects, and how to implement them successfully. Although several studies have explored some of the benefits of certain technologies to motor carriers, thus far, not one has specifically measured the very important link between implementing technology and improving safety for a company. Possible benefits to companies of improving safety, besides the obvious public benefit, include lower overall costs, lower insurance rates, increased productivity, and increased business.

Because of the potential benefits for both the general public and the commercial vehicle industry of improving safety, the overall goal of this project is to identify those technologies that have had a positive impact on the safety of motor carrier companies, and to measure this impact. With this information, an estimate of specific benefits to all partners in the supply chain can be determined. It is anticipated that this information could also be used by the Federal Motor Carrier Safety Administration to aid them in recommending the implementation of technologies that will be of the greatest benefit to both the public and the industry.

This Phase I report contains a brief description of Intelligent Transportation Systems (ITS) and ITS technologies for Commercial Vehicle Operations (ITS/CVO). Second, it discusses previous literature regarding benefits of ITS/CVO for motor carriers, as well as managing the change due to technology. In addition, the possible use of transportation-inventory models as a method to examine benefits is explored. Finally, this methodology is illustrated with a case study analysis which reveals potential savings to both the company and their customers. Phase II of this project will involve data collection for a stratified random sample of carriers nationwide, and a subsequent detailed analysis for a wide variety of technologies and types of companies.

INTRODUCTION

"A diverse set of alliances that includes the Federal Highway Administration, state departments of transportation, manufacturers, business and academia is transforming the technology ideas of tomorrow into the transportation realities of today (1)."

Commercial vehicles transport 6.7 billion tons of freight per year, which represent 60 percent of the total domestic volume of freight shipped. The commercial vehicle industry earns $371.9 billion in gross freight revenues, which equates to 81 percent of the U.S. freight bill (*2*). Since 1980, there has been more than a 75 percent increase in truck traffic, while truckload carriers have experienced more than a 7 percent decrease in their average freight rates (*3*). With the enactment of the Motor Carrier Act of 1980, and the associated alleviation of regulatory entry controls, substantial numbers of carriers have entered the industry contributing to this decline in freight rates. As a result, the truckload sector of the trucking industry is extremely competitive; companies must vie for business through lower rates, and more importantly, superior service (*4*).

One potential strategy for a motor carrier company to better its service offering is through investment in technology. However, as indicated in a recent *Transport Topics* article, "Trucking companies risk being drowned by the flood of technologies and logistics services coming onto the market . . .a quandary for trucking's IT professionals: how to know which technologies will improve the way they do business and which may saddle them with extraneous information . . . to compete, trucking companies will have to provide better, faster service and at less cost" (*5*). As this quote illustrates, commercial vehicle companies are in a precarious position. They realize that they must invest in technology to remain competitive, but are unsure which innovations will give them the desired results.

The right technology can conceivably help a carrier in a variety of ways. For example, computer technology has enabled commercial vehicle routing and scheduling to become routine. Entire supply chains can now be simulated to determine the best approach to meet a company's objectives. The advent of Electronic Data Interchange, the Internet, bar coding, and satellite transmission all have helped to integrate the supply chain and increase its efficiency, as well as effectiveness (*4*).

A company's "bottom line" is impacted not only by reductions in costs, but also by increases in profits, primarily through improved customer service. The right technology, implemented correctly, can affect both areas. Examples of possible affects include improved on-time performance, and improved equipment and driver utilization, as well as reduced en-route delays, accidents, empty miles, and administrative costs.

The main problem is to determine which technologies will contribute to these positive affects mentioned above, and how to implement the technology successfully. Although several studies have explored some of the benefits of certain technologies to motor carriers, thus far, not one has explored the important link between implementing technology and improving safety.

The area of safety, although always a priority, is particularly applicable at the present time. As of January 2000, a new agency, the Federal Motor Carrier Safety Administration (FMCSA), was created within the U.S. Department of Transportation (DOT). This is the only modal administration under the DOT (i.e., among the Federal Aviation Administration, the Federal Highway Administration, the Federal Railroad Administration, the Federal Transit Administration, and the Maritime Administration) that has the word "safety" in its name, and it is to stress its main strategic goal. In fact, Transportation Secretary Rodney Slater has set an ambitious goal to decrease large commercial vehicle-related fatalities by 50 percent by the end of

2009. The initial actions that the FMCSA intends to implement to help achieve this goal are to increase enforcement and safety awareness, to strengthen equipment and operating standards, and to improve information systems and technology (*6*). It is anticipated that the information discovered in the present project will help the FMCSA to target its efforts towards advocating the technologies that will have the greatest impact on safety.

From the motor carrier company perspective, safety is also an important issue. This concern will continue to be the case as the ever-increasing traffic (commercial vehicles and passenger cars) increases the likelihood of accidents. Besides the obvious societal costs of accidents that will impact the company, such as pain and suffering, loss of productivity of anyone injured or killed, police and medical personnel expenses, property damage, traffic delays, etc., there are other important costs to the motor carrier. These costs include damage to the commercial vehicle and cargo, and the necessity to provide another vehicle and/or cargo to complete the delivery. Other consequences may include negative publicity, higher insurance rates, and the loss of future business. For all these reasons, companies are searching for ways that they can use technology not only to provide increased efficiency in their supply chain in today's just-in-time environment, but to help them improve safety.

For the reader unfamiliar with the concept of Intelligent Transportation Systems (ITS) and ITS technologies for Commercial Vehicle Operations (ITS/CVO), the remainder of this introductory chapter relates a brief description. Chapter 2 discusses previous literature regarding benefits of ITS/CVO for motor carriers, with specific emphasis on safety benefits. This chapter also discusses managing the change due to technology, and the possible use of transportation-inventory models as a method to examine benefits. Chapter 3 then delves into a specific case study analysis as an example.

Description of Intelligent Transportation Systems (ITS)

Presently, the majority of technologies available for commercial vehicle operations can be classified under the name of Intelligent Transportation Systems or ITS. As defined in the National ITS Program Plan:

> Despite the fact that the United States has one of the best surface transportation systems in the world, mobility is declining and safety remains a serious problem. Inefficient movement of vehicles reduces productivity, wastes energy, increases emissions, and threatens the quality of life we enjoy. The continued development and maintenance of a safe, efficient, environmentally responsible transportation system is vital to the social and economic health of the nation. Intelligent Transportation Systems (ITS) apply advanced and emerging technologies in information processing, communications, control, and electronics to meet surface transportation needs. ITS, formerly called Intelligent Vehicle-Highway Systems (IVHS), provide a means to address current problems, as well as anticipate and address future demand through an intermodal, strategic approach to transportation. While ITS technology alone cannot solve our problems, it can enable us to re-think our approach to problem solutions, as well as to make current activities more efficient (*7*).

The IVHS (now ITS) program was established by the Intelligent Vehicle Highway Systems Act within the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). The ISTEA authorized $660 million to research, develop, and test ITS applications. Overall, there are more than 400 projects nationwide to test and deploy new ITS technologies (*1*). The specific goals of ITS established by the ISTEA are to:

- Improve the safety of the nation's surface transportation system;
- Increase the operational efficiency and capacity of the surface transportation system;
- Reduce energy and environmental costs associated with traffic congestion;
- Enhance present and future productivity;
- Enhance the personal mobility and the convenience and comfort of the surface transportation system; and
- Create an environment in which the development and deployment of ITS can flourish (*7*).

With these goals in mind, seven main areas consisting of 29 "user services" were conceptualized. These user services are illustrated in Table 1 and are products and services that either have been or may be developed in response to the needs of individuals and organizations. These services and definitions are subject to change over time (*7*).

Description of ITS Technologies for Commercial Vehicle Operations

The ITS technologies currently and potentially available specifically for commercial vehicle operations (CVO) are illustrated under the fifth area in Table 1. The main focus of these user services is to improve fleet management and freight mobility for the private sector, and to make government and regulatory functions more efficient. The vision for the ITS/CVO program is: "Assisted by advanced technology, trucks and buses will move safely and freely throughout North America" (*7*). A brief description of each user service is described.

Table l. ITS User Services

Area	User Services
1. Travel and Transportation Management	1. En-Route Driver Information 2. Route Guidance 3. Traveler Services Information 4. Traffic Control 5. Incident Management 6. Emissions Testing and Mitigation
2. Travel Demand Management	1. Demand Management and Operations 2. Pre-Trip Travel Information 3. Ride Matching and Reservation
3. Public Transportation Operations	1. Public Transportation Management 2. En-Route Transit Information 3. Personalized Public Transit 4. Public Travel Security
4. Electronic Payment	1. Electronic Payment Services
5. Commercial Vehicle Operations	1. Commercial Vehicle Electronic Clearance 2. Automated Roadside Safety Inspection 3. On-board Safety Monitoring 4. Commercial Vehicle Administrative Processes 5. Hazardous Materials Incident Response 6. Freight Mobility
6. Emergency Management	1. Emergency Notification and Personal Security 2. Emergency Vehicle Management
7. Advanced Vehicle Control and Safety Systems	1. Longitudinal Collision Avoidance 2. Lateral Collision Avoidance 3. Intersection Collision Avoidance 4. Vision Enhancement for Crash Avoidance 5. Safety Readiness 6. Pre-Crash Restraint Deployment 7. Automated Highway System

Source: (*7*)

Commercial Vehicle Electronic Clearance

The commercial vehicle electronic clearance service allows commercial vehicles equipped with transponders to be electronically checked for size and weight requirements, operating credentials, and safety while at highway speeds. If all is satisfactory, the vehicle is cleared to bypass the weigh station or port-of-entry. This currently is available through the Advantage I-75 and the Heavy Vehicle Electronic License Plate, Inc. (HELP, Inc.) projects. The Advantage I-75 project clears vehicles through weigh stations along Interstate-75, which runs from Florida through the mid-west into Ontario; while the HELP, Inc. project, through what is termed PrePass, clears vehicles in approximately 15 western and mid-western states (*7*).

Automated Roadside Safety Inspection

The goal of the automated roadside safety inspection service is to provide more selective and quicker roadside inspections of commercial vehicles. This is accomplished through the provision of safety data to inspectors at the roadside and the use of sensors and diagnostic equipment (*7*). As an example, the author was involved in the development and implementation of the Inspection Selection System, which recommends vehicles and drivers for inspection based on their company's prior safety performance and history of inspections. This system currently is in use throughout the United States and has proven to be quite effective at targeting unsafe carriers for inspection (*8*).

On-Board Safety Monitoring

The objective of the on-board safety monitoring service is to have the ability to continuously monitor the driver, the vehicle, and the cargo; and to make notification if an unsafe situation occurs (*7*).

Commercial Vehicle Administrative Processes

The commercial vehicle administrative processes service is designed to allow companies to purchase needed credentials, and to collect and report fuel and mileage tax information electronically (*7*).

Hazardous Materials Incident Response

It is anticipated that the hazardous materials incident response system will provide emergency personnel immediate information regarding the type and quantity of hazardous materials present at the scene of an incident (*7*).

Freight Mobility

The ability to provide information and communication between drivers, dispatchers, and transportation providers defines the freight mobility service. It enables companies to take advantage of real-time traffic and vehicle location information (*7*).

LITERATURE REVIEW

From an extensive literature review and the author's personal conversations and experience in this area, one point is readily apparent. Although there appears to be little disagreement about the *potential* benefits of ITS/CVO, the literature regarding direct measured benefits of these technologies is lacking, especially in the area of safety benefits. A review of the studies related to the benefits of ITS/CVO technologies for motor carrier companies is given below. This is followed by a review of studies that have discussed the change that implementing an ITS technology will bring to the company. Finally, a brief review of the current literature regarding use of transportation-inventory models as a possible way to measure benefits is presented. This literature review is meant to present the important concepts, findings, and areas of research that have been completed and are applicable to the current project.

Benefits of ITS/CVO for Motor Carriers

One of the most comprehensive and often quoted studies regarding benefits of ITS/CVO was conducted by the American Trucking Associations (ATA) Foundation and published in 1996 (*9*). The project surveyed motor carriers and technology vendors to estimate benefits and costs of different ITS/CVO technologies. The results of the study in terms of each of the six commercial vehicle operations user services discussed in Chapter 1 are as follows.

In the Commercial Vehicle Administrative Processes area, for carriers with more than 10 power units, which have regional or national operations, the expected reduction in administrative compliance costs outweigh the costs of participation by at least four to one. There were not

Finally, in the Freight Mobility area, since this is primarily a private sector activity, the study does not give benefit/cost ratios using the same criteria as the other user service areas. Instead, it simply states that there are many examples of improvements in carrier operating efficiency and safety in this area, with associated benefit/cost ratios of up to five to one (*9*).

Some of the limitations of the study, which become opportunities to improve the analysis in future studies, include the following: (1) the estimates are based on potential operating parameters for programs that are not implemented, (2) each user service is examined independently and not in an integrated framework, (3) benefits only are defined in terms of labor cost reductions and *do not include benefits related to increased efficiency or safety,* and (4) the labor cost reductions are estimated by the motor carriers through the survey and are assumed to be reasonable (*9*).

It is interesting to note that even with the conservative estimate of benefits in this study, and the use of actual costs of the technologies, nearly all the user service areas have benefit/cost ratios greater than one to one.

In terms of benefit/cost analyses of ITS/CVO for the motor carrier industry, even with its limitations, the above study is the most thorough to date. The majority of other studies related to the benefits of ITS/CVO approach the analysis from the viewpoint of the benefits to state agencies.

One comprehensive report published at the end of 1997 attempts to consolidate all studies to date that document the experience with, and the prediction of, ITS benefits in every area of ITS (*10*). There was then an update to this report published in 1999, with an associated Internet web site created for continual updates (*11*). The author of this report uses measures created by the Federal Highway Administration to analyze the effects of ITS. These measures are crashes, enough responses from carriers with less than 10 power units that were capable of Electronic Data Interchange to estimate the benefit/cost ratios for this group (*9*).

In the Electronic Clearance area, benefits in terms of reduced cost of driver time only are assumed to apply to motor carriers whose driver settlements are time-based. This assumption efficiently eliminates the majority of truckload carriers — that predominantly pay their drivers on a per-mile basis — from the analysis. For those carriers who pay drivers based on hours worked, the benefits of electronic clearance for carriers of all sizes outweigh the costs by at least two to one (*9*).

Similarly, in the Automated Roadside Safety Inspection area, the benefits measured are assumed to only accrue to those companies that pay drivers on a time basis. The two areas of benefit examined were reductions in the time to undergo a roadside safety inspection and in the time to complete hours-of-service log books and trip reports, both through on-board computers or electronic log books. The calculated benefit/cost ratios for all sizes of carriers in this area was at least 1.3:1 (*9*).

In the area of On-Board Safety Monitoring, consisting of collision avoidance and on-the-road monitoring of drivers and vehicles, benefit to cost ratios in this study only considered the latter component and ranged from only 0.02:1 to 0.49:1. These low ratios are because the only benefits considered were those associated with reduced labor costs of regulatory activities, and other potential benefits of the system were not taken into account (*9*).

When considering the Hazardous Material Incident Response area, benefits exceed costs for carriers with more than 10 power units with a ratio of at least 1.1:1. As with Electronic Clearance, there were not enough EDI-capable small carriers in the survey responses to estimate benefit/cost ratios for this group (*9*).

fatalities, travel time, throughput, user satisfaction or user acceptance, and cost. The report then examines if each of the studies provides measured, anecdotal, and/or predicted benefits in each area. Under commercial vehicle operations, the report states that there have been studies related to the benefits of ITS/CVO which have provided anecdotal evidence regarding crashes; predicted evidence regarding fatalities; measured and predicted documentation regarding time; measured, anecdotal, and predicted documentation regarding cost; and measured and predicted documentation of customer satisfaction. There has been nothing noted in the area of throughput (*10*). Table 2 displays a summary of the ITS/CVO benefits data which the report states is available. Those studies that the report indicates involved implementation of systems by motor carriers are discussed below, the remainder were either evaluations of systems implemented by, or discussions of benefits for, government agencies only.

Table 2. Summary of ITS/CVO Benefits Data Available

Measure	Data Available
Crashes	Anecdotal
Fatalities	Predicted
Time	Measured, Predicted
Throughput	
Cost	Measured, Anecdotal, and Predicted
Customer Satisfaction	Measured, Predicted

Source: (*10*)

In terms of crash reduction, the evidence thus far is only anecdotal that in-vehicle or roadside ITS technologies that identify drivers and vehicles at high risk, and the associated improvement of traffic flow near enforcement areas, will reduce the number of crashes.

Similarly, there have only been predicted benefits of fatality reduction due to ITS/CVO technologies in a 1997 study based on hypothetical usage and changes in inspection practices. The predicted benefit is a potential reduction in fatalities of 14 to 32 percent (*10*). This is the only study to date which directly relates to the present study and attempts to link safety with technology used by the motor carrier. However, the study does not look at specific technologies, but simply uses an estimated market penetration rate for all the ITS/CVO user services and an arbitrary fatal involvement reduction factor to determine the potential reduction in fatalities (*12*).

In the area of time benefits of ITS/CVO, the use of communication and advanced vehicle monitoring technologies have illustrated substantial savings. Some of the companies that have measured and reported their time benefits associated with these technologies are Schneider National, Trans-Western Ltd, Frederick Transport, and Best Line. For example, Schneider reports in a 1992 study that they have been able to save about two hours a day by eliminating driver check-in telephone calls. Similarly, Best Line estimates about a $10,000 savings a month by eliminating driver waiting time to talk with dispatchers (*13*).

In addition, a 1997 simulation study predicted time savings at weigh stations for transponder-equipped vehicles and for non-equipped vehicles. Obviously, transponder-equipped vehicles permitted to bypass the station save 100 percent of the delay time. However, as the percent of transponder-equipped vehicles rises, and queue lengths shorten, non-equipped vehicles also can benefit and save up to an average of eight minutes at the station (*10*).

In the area of cost reduction, there is anecdotal, measured, and predicted benefits. Anecdotal evidence was provided by carriers involved in an operational test of commercial vehicle administrative processes in 1996. They estimated a potential to reduce costs 33 to 50 percent for International Fuel Tax Agreement and International Registration Plan reporting. Measured cost reductions once again were provided by the same carriers mentioned above (obviously, time savings translate into cost reductions). Some of the cost reductions were due specifically to the increase in loaded mileage of 9 to 16 percent, and subsequent decrease in operating costs of $0.12 to $0.20 per truck mile. In addition, decreases in driver turnover also were reported, resulting in another significant cost savings. The majority of the predicted cost benefits are from the 1996 ATA Foundation study discussed previously, however one additional 1995 study did predict some cost savings from the use of real-time traffic diversion of carriers, which resulted in a productivity improvement of 6 percent (*10*).

With regard to customer or user satisfaction, once again the measured benefits here were by the same motor carriers as above with noted benefits of increased loaded miles, improved customer service, decreased driver turnover, and reports of 17 percent more shipments and 4 percent fewer cancellations due to ITS technologies (*13*). In addition, in a 1995 study of 1,500 commercial vehicle drivers, nearly 90 percent viewed some or all of the available CVO services favorably (*10*).

In addition to the above measures, still another benefit noted of ITS/CVO is emissions and fuel consumption reductions. A 1997 study has stated that there is a fuel savings of 0.05 to 0.18 gallons per avoided stop with a preclearance system such as in Advantage I-75 (*10*).

As mentioned previously, nothing has been done to date in measuring the benefits of ITS/CVO in the throughput area (i.e., the number of people, vehicles, or goods moved per unit of time), although this has been alluded to in the evidence of increases in loaded miles. Another area for investigation may be the effect on the reliability of transit times and the associated benefits of this. However, most notably, there has been little investigation into any direct link between specific technologies and safety.

Managing Change Due to ITS/CVO

In addition to the above problem of detailing the safety benefits of ITS/CVO, companies also need to address exactly how they will manage the change that the technology will bring to the company. For example, Swift Transportation, which operates 6,000 vehicles nationwide, implemented a Qualcomm® system to track vehicles and allow drivers and dispatch to communicate. However, in a recent survey, they indicate that some of their drivers cannot use the system correctly as they are not "technically inclined" (*14*). This is another area where the literature regarding ITS/CVO is lacking. An important consideration before implementing any new technology into a company is how those impacted by the technology are going to react to it. If this is not properly considered and implemented, the potential benefits of the system may never materialize. As aptly quoted in an article by Hubbard, ". . . the upper limit to the usefulness of this or any technology is not the hardware or the software itself, but the minds of the people expected to use it" (*15*).

This idea was further emphasized to the author during the 1998 Educator's Conference associated with the Annual Meeting of the Council of Logistics Management. Dr. David Closs, editor of the *Journal of Business Logistics,* stated several times during his presentation that one of the main areas he believed needed more emphasis was the area of implementing technology effectively. He suggested that there should be more insights and guidance into the application of technology, preferably through collaborative research consisting of universities and industry working together. He emphasized that we do not need as much information about the technology itself as we need assistance in how to train people to use it effectively.

Of the reports that were reviewed considering ITS/CVO technologies, only two mentioned the changes technology would bring. One was the above report that documented the problems with Swift Transportation drivers using the technology. This report simply gives the suggestion that drivers should be educated about the system for it to be cost-effective (*14*). The second report, which alludes to the change that technology brings states that ". . . the advantage will go to those who have the perseverance to learn and understand the new technologies and the management skills to apply them" (*16*). Although somewhat obvious, this report also gives more insight into exactly the types of carriers that will benefit most from ITS/CVO technologies. These carriers include those that operate just-in-time deliveries, are long-haul, contract drivers paid per hour, and those that pass the same weigh station(s) repeatedly (*16*).

To help companies understand the types of changes a technology will bring, one could examine literature in management and organizational development. One of the more contemporary theories in this area is contingency theory. In general, this theory acknowledges that organizations are unique and what works well in one environment may not necessarily work well in another. Consequently, there is not one overall "best" way to manage change – it depends on the characteristics of the specific company. For example, particular characteristics that may be examined are the degree of environmental stability (stable or dynamic) and the adaptive orientation or degree of flexibility (low or high) of the organization. Depending on the combination of these characteristics present, there are general approaches to change in the company, which may be more effective than others (*17*).

Use of Transportation-Inventory Models

Although previous researchers have used several methodologies to attempt to estimate the benefits of ITS/CVO technologies, not one has considered borrowing from the literature regarding logistics. As noted by the Council of Logistics Management, logistics is defined as "that part of the supply chain process that plans, implements, and controls the efficient, effective, flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements" (*18*). Logistics provides a holistic system framework for decision making, which considers transportation, inventory, warehousing, materials handling, packaging, etc., and the associated cost and service tradeoffs in every area from any changes that are made in the system. Thus, this seems like an obvious area to research when considering the impact of ITS/CVO technologies on a company.

In fact, one particularly applicable article illustrates how carriers can use information regarding transit time and reliability when bargaining with shippers regarding rates. As stated in the article, "Because the carrier must recover these resource costs, the carrier must be able to estimate the benefit (reduction in distribution costs) to the shipper/receiver in order to determine what the shipper/receiver is able to pay for the improved service" (*19*). This is exactly what commercial vehicle companies considering ITS technologies need to do. They must estimate the benefit that the new technology will provide to their customer (the shipper) and determine what the shipper is willing to pay for this improved service. In addition, the carrier also could estimate the additional market share that this improved service could provide them.

The article illustrates the use of a transportation-inventory model and the associated total distribution costs under differing means and variances of travel times. Placing these into a matrix easily illustrates how much a shipper may be willing to trade to achieve increased reliability and/or transit time (*19*). As an example, refer to Table 3. In the extreme case that the mean travel time is reduced from five to two days and the variance of the travel time is reduced from 0.6 to 0.0, the total distribution cost to the shipper is reduced by $58.86.

Table 3. Example of Total Distribution Cost for Differing Means and Variances of Travel Time

	Variance						
Mean	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
2	$648.63	$657.11	$665.47	$673.64	$681.81	$686.79	$689.34
3	$656.72	$665.54	$674.17	$682.81	$687.81	$691.40	$695.00
4	$666.35	$675.14	$683.84	$688.22	$692.52	$696.83	$701.14
5	$676.82	$683.41	$688.28	$693.08	$697.88	$702.69	$707.49

Source: (*19*)

This idea is further illustrated by Tyworth and Zeng in a more recent article, which extends and improves on the analysis (*20*). As detailed in the paper, the expected total annual logistics cost (ETAC) can be expressed as the sum of transportation, holding, ordering, and shortage costs as follows:

$$ETAC(s,Q) = \left[f(Q)(1-d)R\frac{w}{100} \right] +$$
$$\left[\mu_T \mu_D \bullet V \bullet Y + \left(\frac{Q}{2} + s - \mu_X \right) V \bullet W \right] + \left[A\frac{R}{Q} \right] + \left[ES \bullet B_2 V \frac{R}{Q} \right]$$

where $f(\cdot)$ = continuous functional relationship between the freight rate and lot size,
d = percentage discount offered by the carrier,
R = annual demand,
w = weight,
μ_T = mean transit time,
μ_D = mean demand per period,
V = value or standard cost of inventory item,
Y = annual carrying cost factor for in transit stock,
Q = fixed order quantity,
s = reorder point,
μ_X = mean lead-time demand,
W = annual carrying cost factor for warehouse stock,
A = order processing cost,
ES = expected shortages per replenishment cycle, and
B_2 = pre-specified fraction of unit value charged per unit short.

The obvious objective is to minimize this function by changing the decision variables *s* (the reorder point) and *Q* (the order quantity). Using this type of formulation, one could easily determine the effect that changes in the mean and/or the variance of the transit time could have on the total annual logistics costs. Tyworth *et al.* also has illustrated previously how this formulation can be readily solved using popular spreadsheet programs (*21*).

Summary

In conclusion, literature has been reviewed in this chapter regarding the benefits of ITS/CVO to motor carrier companies, the change technology brings to the company, and the application of a transportation-inventory model for potentially measuring the effect of a change in transit time and/or reliability on annual logistics costs. Areas have been identified where the literature is lacking, particularly in estimating direct safety benefits of ITS/CVO technologies for motor carrier companies, and illustrating how to effectively implement the technology into the company and manage the change it will bring.

CASE STUDY ANALYSIS

Because of the importance of safety, and the potential benefits for both the general public and the commercial vehicle industry of improving safety, the main goal of this project is to identify those ITS/CVO technologies that have had a positive impact on the safety of motor carrier companies, and to measure this impact. With this information, an estimate of specific benefits to all partners in the supply chain can be determined. As described in the introductory chapter, the benefits to companies of improving safety, besides the obvious public benefit, include lower overall costs, lower insurance rates, increased productivity, and increased business. It is anticipated that this information also could be used by the FMCSA and motor carrier companies to aid them in implementing technologies that will be of the greatest benefit to both the public and the industry. In addition, in order that the technology be implemented and used successfully, suggestions for facilitating the change it will bring to a company will be identified.

This Phase I report will identify the methodology to accomplish the above objectives, and present an illustration with a case study analysis.

Methodology

With the research problem clearly defined, it is important to examine the specific variables of interest for this study. The obvious dependent variable of interest is the safety of motor carrier companies. Not so obvious, however, is exactly how to measure safety. Normally, one defines safety by accidents; however, accidents are caused by many factors that may not necessarily be related to the company itself (i.e., the weather, road conditions, other drivers' actions, etc.). In addition, the only database that links accidents to specific motor carriers is maintained by the Federal Motor Carrier Safety Administration (FMCSA) – and the FMCSA is the first to admit that there are serious under reporting problems in the data. The FMCSA receives information from the states each year regarding approximately 100,000 reportable accidents, but the belief is this is about 50,000 under what it should be. In addition, some of the accident data submitted is inaccurate and/or incomplete (*22*). Therefore, given the problems associated with using accident data, a better substitute for the measure of safety should be used. One possible measure is the company's roadside inspection out-of-service rate or violation rate.

One of the main commercial vehicle safety activities of the FMCSA is to conduct roadside inspections. Roadside inspections follow a standard known as the North American Standard which was developed by the Commercial Vehicle Safety Alliance in cooperation with the Federal Highway Administration. Inspections involve an examination of vehicles, drivers, and hazardous material cargo; and focus on critical safety regulations. They include provisions for placing vehicles and/or drivers out-of-service (OOS) if unsafe conditions are discovered. These problems must be corrected prior to the continuation of a trip (*23*).

Data obtained from roadside inspections of motor carriers are input, or uploaded from a computer, by the states locally into an information system termed SafetyNet. The states then transmit relevant data for carriers electronically to the Motor Carrier Management Information System (MCMIS) at FMCSA headquarters.

There are two reasons to justify the use of the out-of-service and/or violation rates as a measure of safety. First, these rates have been illustrated in previous research to be significantly positively correlated with accident rates – i.e., companies with higher out-of-service or violation rates also tend to have higher accident rates (*24*). Second, companies and drivers are required to be knowledgeable of the regulations, and to examine their equipment before every trip to ensure that there are no violations. Therefore, when a vehicle or driver violation is found during a roadside inspection, it is a direct reflection on the company. Thus, the higher the number of violations and/or out-of-service orders a company has, the more unsafe that company is likely to be.

Specifically, the possible dependent variables of interest, then, are the driver and vehicle out-of-service rates (calculated as the number of out-of-service inspections divided by the total number of inspections); and the driver and vehicle violation rates (calculated as the number of violations discovered during inspections divided by the total number of inspections). In addition, another advantage of using violation rates is that there are specific categories of violations that can be used. For vehicle violations, these categories include brakes, tires/wheels, and steering/suspension. For driver violations, the categories include no/improper medical certificate, no/false log book, hours-of-service rule violations, disqualified driver, drugs/alcohol, and traffic enforcement. The data for these dependent variables is readily available through the FMCSA.

The other variables of interest include which technologies, if any, the company is using, how long the technology has been in place, as well as demographic characteristics such as the size of the company (measured by the number of power units and drivers), whether the company is truckload or less-than-truckload, private or for-hire, and the type of cargo generally carried. This information will be collected via survey to a stratified random sample of the interstate motor carrier population. This survey and subsequent analysis will be conducted in Phase II of this project.

Case Study

Werner Enterprises was selected as an ideal motor carrier company for a case study analysis because of its recent highly publicized implementation of electronic logbooks. The author personally visited with Werner at their headquarters in Omaha, Neb., early September 1999. While there, interviews were conducted with the Director of Technical Services, the Director of Driver Relations, the Vice President for Safety, employees working directly with the driver logs, as well as with a few drivers. The following information was obtained during the course of these interviews.

Werner started business with a single truck in 1956, and has grown to operating 7,200 power units and employing 8,500 drivers today. It is a for-hire, interstate trucking company, which hauls primarily general freight. Development of the electronic logbook system began in 1994, and was first tested with a limited number of drivers in 1996. The company used both the normal paper logs and the electronic logs until it received a waiver from the Department of Transportation in June 1998 to allow its drivers to drive without the paper logs.

Werner claims that the benefits of the electronic logs include: increased driver productivity, efficiency, and retention; as well as better load planning and customer service. The drivers also appear to like its convenience and ease of use. One new driver stated that he had never even used a paper logbook before and could not imagine doing so.

When asked about the concern of managing the change that this new technology brought to the company, the Vice President for Safety admitted that it was somewhat of a dramatic culture change. This was a whole new way for the driver to conduct his/her business. He stated that there was, and still is, an educational process established that the Chairman of the Board steers directly. Drivers are offered plenty of opportunity to ask questions and state any concerns, and are given a significant amount of training.

Applying the above knowledge to the methodology discussed previously, it is desired to determine whether or not Werner's electronic logbook technology has had an impact on their safety in terms of their driver violation and out-of-service rates. Table 4 displays the log book violation rate, the hours-of-service violation rate, and the driver out-of-service rate for Werner, as well as for six other trucking companies that are similar in size and operation. Werner is the only one that currently is using the electronic logbook technology.

Examining the June 2000 data, the average log book violation rate for Werner was 0.026, while the average for the six other companies was 0.255; the average hours-of-service violation rate for Werner was 0.004, but was 0.038 for the other six; and the average driver out-of-service rate was 0.018 for Werner, and was 0.070 for the other six companies.

Although not needed for the analysis, the June 1996 data for all the companies also is presented in Table 4. No other company experienced as significant a drop in their driver violation and out-of-service rates as Werner, and a few actually have worse rates today than in 1996.

Table 4. Specific Companies and Violation Rates

Company / Rates	June 2000	June 1996
Werner Enterprises		
Log Book Violation Rate	0.026	0.146
Hours-of-Service Violation Rate	0.004	0.028
Driver Out-of-Service Rate	0.018	0.045
Schneider National		
Log Book Violation Rate	0.197	0.230
Hours-of-Service Violation Rate	0.024	0.023
Driver Out-of-Service Rate	0.047	0.056
J. B. Hunt		
Log Book Violation Rate	0.250	0.269
Hours-of-Service Violation Rate	0.023	0.038
Driver Out-of-Service Rate	0.058	0.078
Landstar Ranger		
Log Book Violation Rate	0.333	0.318
Hours-of-Service Violation Rate	0.034	0.036
Driver Out-of-Service Rate	0.090	0.103
Swift Transportation		
Log Book Violation Rate	0.201	0.197
Hours-of-Service Violation Rate	0.030	0.036
Driver Out-of-Service Rate	0.053	0.074
U. S. Xpress		
Log Book Violation Rate	0.264	0.216
Hours-of-Service Violation Rate	0.050	0.032
Driver Out-of-Service Rate	0.073	0.069
CR England		
Log Book Violation Rate	0.286	0.321
Hours-of-Service Violation Rate	0.064	0.053
Driver Out-of-Service Rate	0.097	0.111

To place a monetary amount to the safety benefits that Werner is experiencing due to their logbook technology, information will be used from a journal article published by Moses and Savage (1997) (*26*). In this article, the authors conduct a cost-benefit analysis of the federal compliance audit program and the roadside inspection program. During the course of the analysis for the roadside inspection program, the authors calculate costs to motor carriers of roadside inspections. The authors estimate that an average roadside inspection delays a commercial vehicle by about 31.5 minutes. However, when a driver out-of-service violation is found, this delay increases to approximately four hours on average (*26*). At 50 miles per hour, this would equate to about 200 miles lost.

The difference between Werner's driver out-of-service rate and the average of the six other similar companies was 0.052. Therefore, in general, Werner had about 5.2 percent fewer drivers placed out-of-service than other companies. Werner had 11,024 driver roadside inspections in the two years prior to June 2000, and had 194 drivers placed out-of-service. If they would have had a driver out-of-service rate 5.2 percent higher, this would have translated into 578 more drivers placed out-of-service. This in turn would have amounted to approximately 2,312 additional hours lost and 115,600 additional miles lost. Werner was unable to disclose specific financial information, but the average operating cost per mile for the for-hire truckload industry is about \$1.36 (*27*). Therefore the total operating cost savings to Werner is approximately \$157,216.

Determining how much benefit there is to Werner in terms of accident reduction is slightly more challenging. Moses and Savage (1997) estimate that when a driver is placed out-of-service, there is a potential accident reduction factor of about 4.27 percent (*26*). This could be interpreted that approximately 4.27 percent of those drivers put out-of-service for a driver violation would have been involved in an accident had they not been put out-of-service. Because Werner had 578 fewer drivers placed out-of-service, the conclusion is that they potentially also had about 25 fewer driver-related accidents. Moses and Savage (1997) estimate the total cost of an average truck accident to be $118,211 (*26*). Therefore, Werner has also saved approximately $2.96 million in reduced accident costs.

The discussion thus far has only concentrated on savings to Werner, but there also are obvious benefits to their customers in terms of transit time and reliability. Of course, this improved customer service also will benefit Werner with increased customer satisfaction and subsequent business. To observe the effects of improved transit time and reliability, the transportation-inventory model discussed in Chapter 2 will be used.

A spreadsheet adaptation of the transportation-inventory model is displayed in Tables 5 and 6. This model formulation was based on material authored by Tyworth, Rao, and Stenger (1991) (*21*). The inputs for the model are displayed in Table 5, while the problem formulation, working formulas, and solution are displayed in Table 6. By changing the inputs of the model, in particular, the probability distribution of the lead time variable, one can illustrate the effect on the shipper's total logistics costs from an improvement in transit time and reliability.

The inputs listed for the model in Table 5 were obtained from an article by Tyworth and O'Neill (1997) (*28*). The data represent an example from the electronics industry, which is one industry that Werner generally serves. It should be noted that this model is most applicable for fast-moving demand items. It assumes a single-echelon continuous-review inventory system and a single, independent-demand item, which is transported via truck over a particular lane (the present example uses the rate data from a leading national trucking company for a predominate 300-mile route) (*28*).

As illustrated in Table 6, given the inputs listed in Table 5, the optimal order quantity is 524 units, and the reorder point is when inventory drops to 570 units. This will ensure a 99.9 percent probability of not having a stockout occur. Under this scenario, the total logistics cost (which include the order cost, cycle stock cost, in-transit stock cost, and safety stock cost) is about $5,374 annually per product per customer.

To illustrate the effect of decreased transit time and increased reliability on the logistics costs, Table 7 displays a change in the probability distribution of the lead time variable. Specifically, it is assumed that 5 percent fewer deliveries took up to 14 days, and, subsequently, 5 percent more deliveries were completed in seven days. This change was selected to approximate the increase in reliability and decrease in transit time that Werner's customers may experience due to the five percent fewer drivers that Werner has placed out-of-service.

Table 8 illustrates results of the change in the probability distribution of lead time. The mean lead time decreased from 7.00 days to 6.65 days, and the standard deviation decreased from 2.15 to 1.42. In addition, although the number of orders per year and the order quantity did not change, the reorder point necessary to maintain the same no stockout target decreased from 570 to 456 units. This obviously effects the in-transit and safety stock levels, and those associated costs. This ultimately translates into an approximate 8.7 percent decrease in total logistics costs.

Table 5. Inputs for the Transportation-Inventory Model

Inventory System Parameters	Symbol	Value
Mean period demand	UD	34.00 units
Standard deviation of demand	SD	13.60 units
Unit weight	Wt	0.50 lb
Unit value	V	$17.09
Holding cost factor - warehouse	W	25%
Holding cost factor - transit	Y	15%
Order / Setup cost	A	$25.00
Order processing periods	OT	1 days
Periods per year	DPY	365 days
No stockout target	P1_	99.9%
Transportation Option		
Shipping Cost: $F=A\_*(Q*Wt)^{B-}$		
Power function parameter	A_	306.94
Power function parameter	B_	-0.3071
Negotiated discount	d	50%
Class of freight	Class	100
Lead time (transit time + OT)	pmf	
	0	p(t)
	1	0.00
	2	0.00
	3	0.02
	4	0.05
	5	0.05
	6	0.16
	7	0.65
	8	0.00
	9	0.00
	10	0.00
	11	0.00
	12	0.00
	13	0.00
	14	0.07

Table 6. Problem Formulation, Working Formulas, and Solution for the Transportation-Inventory Model

Problem Formulation			**Working Formulas**		
Decision Variable	Symbol	Value	Element	Symbol	Value
Order quantity	Q	524	Transit time		
Objective Function			Mean	UT	6.00
MIN: total annual logistics cost	ETAC	$5,373.78	Standard deviation	ST	2.15
			Lead Time (L)		
			Mean	UL	7.00
Solution			Standard deviation	SL	2.15
s*		570	Demand During Lead Time (X)		
Q*		524	Mean	UX	238.00
ETAC*		$5,373.78	Standard deviation	SX	81.36
			Procurement		
			Orders/year	RY	24
			Transportation		
			Ship weight	SW	262 lb
			Effective freight rate	F	$27.75 /cwt
			Other		
			Gamma parameter of X	Alpha	8.56
			Gamma parameter of X	Beta	27.81
			Reorder point	s	569.67
Standard Deviation of Lead Time			Annual volume	R_	12,410 units
0.00			Stock Levels		
0.00			Cycle stock	CS	262 units
32.00			In-transit stock	IS	204 units
45.00			Safety stock	SS	332 units
20.00			Cost Analysis		
16.00			Transportation	TC	$1,721.83
0.00			Procurement		
0.00			Acquisition	AC	$212,086.90
0.00			Order / Setup	OC	$591.58
0.00			Inventory		
0.00			Cycle stock	CSC	$1,120.35
0.00			In-transit stock	ISC	$522.95
0.00			Safety stock	SSC	$1,417.07
343.00			Total logistics cost	ETAC	$5,373.78
456.00	2.15		Total cost with acquisition	ETACA	$217,460.68

Table 7. Adjusted Inputs for the Transportation-Inventory Model

Inventory System Parameters	Symbol	Value
Mean period demand	UD	34.00 units
Standard deviation of demand	SD	13.60 units
Unit weight	Wt	0.50 lb
Unit value	V	$17.09
Holding cost factor - warehouse	W	25%
Holding cost factor - transit	Y	15%
Order / Setup cost	A	$25.00
Order processing periods	OT	1 days
Periods per year	DPY	365 days
No stockout target	P1_	99.9%
Transportation Option		
Shipping Cost: $F=A\_*(Q*Wt)^{B-}$		
Power function parameter	A_	306.94
Power function parameter	B_	-0.3071
Negotiated discount	d	50%
Class of freight	Class	100
Lead time (transit time + OT)	pmf	
	0	p(t)
	1	0.00
	2	0.00
	3	0.02
	4	0.05
	5	0.05
	6	0.16
	7	0.70
	8	0.00
	9	0.00
	10	0.00
	11	0.00
	12	0.00
	13	0.00
	14	0.02

Table 8. Adjusted Problem Formulation, Working Formulas, and Solution for the Transportation-Inventory Model

Problem Formulation			**Working Formulas**		
Decision Variable	Symbol	Value	Element	Symbol	Value
Order quantity	Q	524	Transit time		
Objective Function			Mean	UT	5.65
MIN: total annual logistics cost	ETAC	$4,906.44	Standard deviation	ST	1.42
			Lead Time (L)		
			Mean	UL	6.65
Solution			Standard deviation	SL	1.42
s*		456	Demand During Lead Time (X)		
Q*		524	Mean	UX	226.10
ETAC*		$4,906.44	Standard deviation	SX	59.59
			Procurement		
			Orders/year	RY	24
			Transportation		
			Ship weight	SW	262 lb
			Effective freight rate	F	$27.75 /cwt
			Other		
			Gamma parameter of X	Alpha	14.40
			Gamma parameter of X	Beta	15.70
			Reorder point	s	455.53
Standard Deviation of Lead Time			Annual volume	R_	12,410 units
0.00			Stock Levels		
0.00			Cycle stock	CS	262 units
26.65			In-transit stock	IS	192 units
35.11			Safety stock	SS	229 units
13.61			Cost Analysis		
6.76			Transportation	TC	$1,721.83
8.58			Procurement		
0.00			Acquisition	AC	$212,086.90
0.00			Order / Setup	OC	$591.58
0.00			Inventory		
0.00			Cycle stock	CSC	$1,120.35
0.00			In-transit stock	ISC	$492.45
0.00			Safety stock	SSC	$980.23
108.05			Total logistics cost	ETAC	$4,906.44
198.75	1.42		Total cost with acquisition	ETACA	$216,993.34

Conclusion

This chapter discussed the methodology used to identify those ITS/CVO technologies that have a positive impact on the safety of motor carrier companies, and to measure this impact for all partners in the supply chain. The methodology was illustrated through a case study example with Werner Enterprises. The case study revealed a potential operating cost savings from improving safety (through electronic driver logbooks) of more than $150,000 and a potential reduction in accident costs of $2.96 million. In addition, an estimate of savings for Werner's customers (from improved transit time and reliability) is approximately an 8.7 percent decrease in their total logistics costs. The second phase of this project will involve data collection for a stratified random sample of carriers nationwide, and a subsequent detailed analysis for a wide variety of technologies and types of companies.

REFERENCES

(1) Reed, James B., Janet B. Goehring, and Chris Pattarozzi. "Intelligent Transportation in America: Prospects and Perils." *Transportation Series,* No. 1, January 1996.

(2) *American Trucking Trends.* 1999 Edition. American Trucking Associations, Inc., Alexandria, Virginia.

(3) *Transportation in America.* 15th Edition. Eno Transportation Foundation, Inc., Lansdowne, Virginia.

(4) Coyle, John J., Edward J. Bardi, and C. John Langley, Jr. *The Management of Business Logistics.* 6th Edition. West Publishing Company, St. Paul, Minnesota.

(5) Whitten, Daniel L. "Parting the Information Technology Sea." *Transport Topics,* June 14, 1999.

(6) Federal Motor Carrier Safety Administration Internet web site, June 2000, http://www.fmcsa.dot.gov/sap/stratplan.htm.

(7) Euler, Gary W. and H. Douglas Robertson. Editors. *National ITS Program Plan.* 1st edition, March 1995.

(8) Lantz, Brenda M., Michael Blevins, and Thomas Hillegass. "An Evaluation of the Roadside Inspection Selection System for Commercial Vehicles." *Transportation Research Record,* No. 1595, 1997.

(9) American Trucking Associations Foundation, Inc. "Assessment of Intelligent Transportation Systems / Commercial Vehicle Operations User Services: ITS/CVO Qualitative Benefit/Cost Analysis." Alexandria, Virginia, 1996.

(10) Proper, Allen T. and Melvyn D. Cheslow. "ITS Benefits: Continuing Successes and Operational Test Results." Mitretek Systems, Inc., Washington, D.C., October 1997.

(11) Mitretek Sytems, Inc. ITS Benefits Evaluation Database Internet web site, June 2000, http://idf.mitretek.org/its/benicost.nsf/frm/entrance.

(12) Evanco, William M. "The Impact on Fatal Involvements of Commercial Vehicle Operation ITS User Services." Mitretek Systems, Inc., Washington, D.C., January 1997.

(13) Morlok, Edward K. and Susan F. Hallowell. "Reported Benefits of Advanced Vehicle Tracking and Communications Systems." Department of Systems, University of Pennsylvania, Philadelphia, September 1989.

(14) Peoples, Melisa D. "In-Vehicle Information Systems For Commercial Vehicle Operations (CVO)." *Compendium: Graduate Student Papers on Advanced Surface Transportation Systems.* Texas Transportation Institute, August 1998.

(15) Hubbard, Andrew S. "The Human Side of Technology." *Mortgage Banking,* Volume 55, Issue 7, April 1995.

(16) Grenzeback, Lance R. "Intelligent Transportation Systems for Motor Carriers: The Winner's Circle or the Four Horsemen of the Apocalypse?" Cambridge Systematics, Inc., Cambridge, Massachusetts, 1996.

(17) Harvey, Donald F. and Donald R. Brown. *An Experiential Approach to Organization Development.* 3rd edition. Prentice Hall, Englewood Cliffs, New Jersey.

(18) The Council of Logistics Management Internet web site, http://www.clm1.org/.

(19) Allen, Bruce W., Mohamed M. Mahmoud, and Douglas McNeil. "The Importance of Time in Transit and Reliability of Transit Time for Shippers, Receivers, and Carriers." *Transportation Research Forum,* 1985.

(20) Tyworth, John E. and Amy Zhaohui Zeng. "Estimating the Effects of Carrier Transit-Time Performance on Logistics Cost and Service." *Transportation Research,* Volume 32, No. 2, 1998.

(21) Tyworth, John E., Kant Rao, and Alan J. Stenger. "A Logistics Cost Model for Purchasing Transportation to Replenish High Demand Items." *Journal of the Transportation Research Forum,* Volume 32, No. 1, 1991.

(22) Ralph Craft, Transportation Specialist, Federal Motor Carrier Safety Administration, Data Analysis Division. Personal conversation, May 2000.

(23) Sienicki, Dale. Editor. *Motor Carrier Safety Analysis, Facts, and Evaluation (MCSAFE).* Volume 3, No. 1, October 1997. Published by the Federal Motor Carrier Safety Administration, Data Analysis Division.

(24) Jack Faucett Associates. *Evaluation of Vehicle Out-of-Service Criteria,* Contract Number DTFH61-89-C-00062, Federal Highway Administration, Washington, D.C., May 1991.

(25) Scheaffer Richard L., William Mendenhall III, and Lyman Ott. *Elementary Survey Sampling.* 5th Edition. Wadsworth Publishing Company, Belmont, California.

(26) Moses, Leon N. and Ian Savage. "A Cost-Benefit Analysis of United States Motor Carrier Safety Programs," *Journal of Transport Economics and Policy,* Volume 31, Number 1, 1997.

(27) Coyle, John J., Edward J. Bardi, and Robert A. Novack. *Transportation.* 5th Edition. South-Western College Publishing, Cincinnati, Ohio.

(28) Tyworth, John E. and Liam O'Neill. "Robustness of the Normal Approximation of Lead-Time Demand in a Distribution Setting." *Naval Research Logistics,* Volume 44, pp. 165-186, 1997.